"On the Electric Equilibrium of the Sun." By SVANTE ARRHENIUS. Communicated by Sir WILLIAM HUGGINS, Pres. R.S. Received and read June 2, 1904.

In recent years many attempts have been made to apply the pressure of radiation, that is a consequence of the theories of Maxwell and Bartoli, to the explanation of cosmical phenomena. Especially the enigma of the nature of comets' tails has been elucidated from this new point of view.

In a memoir presented to the Swedish Academy of Sciences in 1899, I pointed out that several electric and magnetic phenomena, especially auroras and magnetic storms, might also be connected with the pressure of radiation. C. T. R. Wilson found that the negative ions condense vapours more easily than do positive ions. Without doubt the gases in the atmosphere of the sun are practically ionised by the ultra-violet radiation. Therefore we have to suppose, that among the little drops formed by condensation in the sun's atmosphere far more are negatively charged than are positively charged. As these drops are driven away by the pressure of radiation they charge with negative electricity the atmospheres of celestial bodies, *e.g.*, the earth, which they meet, till the charge is so great that discharges occur, and cathode rays are formed, which carry the charge back to the universe.

A calculation of the speed, with which these particles move through space, will not be without interest. Suppose first, for simplicity, that the pressure of radiation is double that of the weight of the particles in the neighbourhood of the sun. It is not difficult to calculate, that in this case the time, necessary for the particle's passage from the surface of the sun to the earth, amounts to 68·7 hours. The specific weight is supposed to be that of water.

Now, after Schwarzschild's calculations, a perfectly reflecting drop

will be driven away with the greatest force from the sun if its circumference is just as great as the wave-length of the radiation. The wave-length of the maximal radiation of the sun is about 0·5 μ. Therefore the optimal dimension for a drop, that is driven away by the pressure of radiation, will be about 0·06 μ. If we suppose a specific weight of the drop like that of water, the repulsive force for a perfectly reflecting drop amounts to about ten times its weight. For a perfectly black drop it is half as great. Now, most drops are neither perfectly reflecting nor perfectly black. Most fluids absorb nearly completely the non-luminous radiation, and reflect a part of the other. An appreciation of these two factors leads to the estimation that the effect for the translucent fluids will be about half as great as for a perfectly black body, *i.e.*, about 2·5 times greater than the gravity against the sun. Such a particle will move away from the sun with 1·5 times greater speed than that calculated above, *i.e.*, it will reach the earth in about 46 hours.

Of course, there may be represented speeds that are more than the double this for drops of low specific weight (compounds of carbon and hydrogen). On the other hand, the speed may be extremely little (or negative), for drops of high specific weight (*e.g.*, gold). This will also be the case for great or very small drops, as Schwarzschild has shown.

These figures have recently acquired a great interest through the discussion by Ellis, Maunder, and Riccò of the connection between sunspots and magnetic storms. Riccò had already, in 1892, stated that in six cases of very strong magnetic storms, these appeared in mean 45·5 hours after the passage of a great sunspot over the central meridian of the sun. In one case the difference of time was only 20 hours.

From the researches of Ellis and Maunder it appears that the magnetic storms *commence* in mean 26 hours after the great groups of sunspots, which probably caused them, had passed the central meridian of the sun. Riccò applies a correction to these figures. He says that in mean the great magnetic storms, quoted by Ellis and Maunder, lasted for 33 hours, and therefore it is natural to assume that the maximum of the magnetic storm, which will probably fall near its middle, arrives 16·5 hours after its commencement. It will, therefore, be nearly true that the maximum of the magnetic storms observed by Ellis, came $26 + 16{\cdot}5 = 42{\cdot}5$ hours after the passage of the corresponding spot through the central meridian of the sun. The figure very nearly coincides with those of Riccò and also with that calculated above. Riccò also makes the observation that the velocity of the small particles, which in my opinion cause the auroras and the magnetic storms, is of the same order of magnitude as the observed velocity with which the cause of these perturbations moves from the sun.

If the sun only emitted negatively electrified particles on all sides, it would soon assume so great an electric charge of positive sign, that the electric forces would hold the negative particles back in the neighbourhood of the sun. There must, therefore, be some cause that carries back as much negative electricity to the sun as it loses through the emission of negative particles. In supposing the least negative charge to be the same as the positive one of a hydrogen atom, weighing 8×10^{-25} gramme, it may be calculated that the force with which this is drawn back to the sun by a potential slope of 3000 volts per cm., amounts to 23·2 dynes. A drop of radius 0·08 μ, of the specific weight of water, has the weight 59×10^{-10} dyne at the surface of the sun. Its repulsion by the pressure of radiation is about 2·5 times greater, 148×10^{-10} dyne. The electric attraction is therefore only about the fourth part of the total force by which the drop is driven away from the sun; therefore its speed is only three-fourths of that calculated before. It is evident that if the electric charge of the sun, or rather of its upper atmosphere, is much greater (about four times) than that supposed, no negatively charged particles can be emitted from the sun. On the other hand, if the sun's charge is less, the particles will move with a speed that is nearly independent of the magnitude of the charge. Probably the charge of the sun in times of great emission, *i.e.*, at sun-spot maxima, will be of this order of magnitude, and in times of sun-spot minima somewhat less.

The charged particles are driven out to all sides from the sun. It might, perhaps, be expected that they would lose their electric charge under the influence of the strong ultra-violet radiation from the sun. But the circumstances must be other for these small particles than for great pieces that are examined in our laboratories. Otherwise it would be impossible to conceive that drops are condensed at all on the negatively charged electrons under the influence of ultra-violet light.*

But if many drops agglomerate together, the potential increases and greater pieces are formed, which can lose their charge gradually. According to the experiments of Elster and Geitel, and Lenard, these charged bodies part slowly with their negative charge in the form of electrons that traverse space.

The path of these electrons is now influenced by the strongly positively charged suns. Their paths become by this influence curved, and they describe hyperbolas round the suns. If their perihelial distance is less than the sun's radius, they fall down on the sun, and diminish its positive charge.

If we now suppose the electric charge of the sun to be just as great

* As the first drops contain only one elementary charge of electricity, they would lose their whole charge at once at a discharge. Perhaps this circumstance causes the difference for elementary and great charges.

as assumed above, we find that electrons moving with the velocity of light are caught by the sun, if the asymptote of their hyperbolic path is less distant from the sun than 2420 times the mean distance of the earth from the sun (or one twenty-fourth of a light-year). This limit distance is inversely proportional to the velocity of the electrons, and nearly proportional to the square-root of the charge of the sun. As now, according to the researches of Lenard, the electrons from a negatively electrified body possess a much less velocity than light, this distance is really much greater than that just calculated.

If, for instance, the velocity of the electrons is the thirtieth part of that of light, a number that is in good agreement with Lenard's measurements, all electrons from space which came along a path that is less distant than 1·25 light-year from the sun, will be caught by the sun. Of course the electrons move with different velocity, so that the said distance may only be regarded as a mean, or as representing the order of magnitude.

Now our nearest star (α Centauri) is distant from us by about 4 light-years, and other stars lie within less than 10 light-years. Thus it is evident that the negative electrons, which are sent off from aggregates of negatively charged drops (these aggregates are probably identical with what we call cosmic dust or meteorites), can in general not pass by many suns without being caught by them. And on the other hand the suns recover in mean from space as much negative electricity as they lose. The electric charges of the suns are in this respect very effective regulators. If the charge is quadrupled the mean distance of the caught electrons is doubled, or, in other words, as they are uniformly disseminated in space, their quantity is quadrupled. Therefore the supply of negative electricity to the suns is proportional to their defect thereof.

From these considerations we see that a very effective balance of gains and losses of negative electricity is maintained. Evidently this balance depends upon the supposition that for the particles that drive away from the sun, other forces than the electric, viz., the pressure of radiation, are preponderating, whilst for the negative electrons caught by the sun, other forces than the electric are wholly insignificant compared with these.

If one supposed, as some authors do, that the negative electricity was carried away from the sun by means of cathode rays, an effective circulation like that described above would be wholly impossible.

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CONTENTS.

"On the Relation between the Spectra of Sunspots and Stars." By Sir NORMAN LOCKYER, K.C.B., LL.D., F.R.S. Received June 8,—Read June 16, 1904.

As the period throughout which the observations of widened lines have been made at South Kensington now includes two maxima and three minima epochs of solar activity, it has seemed desirable to discuss the results obtained, taking into account the chemical origins of the lines affected in passing from the photosphere to the sunspot nuclei. This is going on, but in anticipation of its publication, I desire to direct attention to one of the conclusions arrived at in its bearing upon the question of the temperature conditions of the Arcturian and lower type stars, which formed part of the subject of a recent paper.*

Since 1894, when the last discussion of the widened line results was published,† nearly 10,500 observations of lines in sunspot spectra have been made at South Kensington. An analysis of these lines, in respect to their origins, shows that *the elements chiefly affected during the period* 1892—1903, *inclusive, were Vanadium and Titanium.*

The great importance of Vanadium and Titanium in sunspot spectra has also been demonstrated by Father Cortie during his observations in the B—D region at Stonyhurst.‡

It was foreshadowed in a previous paper on the chemical classification of the stars§ that it seemed probable that, as the result of further work, the "genera" then proposed might have to be split up into "species." During the more recent research mentioned above the temperature classification was tested by comparing the relative intensities of the red and ultra-violet ends of the spectra of stars, situated on various horizons of the temperature curve, including Capella and Arcturus, which, according to the original general classification, belong to the same type, viz., "Arcturian." It was found that the spectrum of Capella extended on an average about 70 tenth-metres further into the ultra-violet than that of Arcturus, whilst the red portion of the spectrum is certainly stronger in the latter. That is to say, *the general temperature of Arcturus is probably appreciably lower than that of Capella.*

The next step was to see if chemical change accompanied this reduction of temperature, and if so, whether the change was in any way related to the change from the photosphere to the sunspot spectrum.

* 'Roy. Soc. Proc.,' vol. 73, pp. 227—238, 1904.

† 'Roy. Soc. Proc.,' vol. 57, p. 199, 1894.

‡ 'Monthly Notices (R.A.S.),' vol. 63, No. 8, pp. 479—480, June, 1903.

§ 'Roy. Soc. Proc.,' vol. 65, p. 191, 1899.